GNSS Solutions:

Repeaters, Pseudolites, and Indoor Positioning

"GNSS Solutions" is a regular column featuring questions and answers about technical aspects of GNSS. Readers are invited to send their questions to the columnist, **Dr. Mark Petovello**, Department of Geomatics Engineering, University of Calgary, who will find experts to answer them. His e-mail address can be found with his biography at the conclusion of the column.

What is GNSS repeater-based positioning and how is it different from using pseudolites?

A GNSS repeater is just like a cellular phone repeater that is used to boost the cell phone reception by using a reception antenna, a signal amplifier and an internal rebroadcast antenna. In contrast to cellular broadcast stations, GNSS repeaters are much smaller and often installed inside buildings with an external reception antenna collecting the satellite signals.

By installing a GNSS repeater, we can receive live GNSS signals even in indoor environments. However, as is well known, the indoor position solution determined with a GNSS receiver using a repeater signal is actually the location of the outdoor reception antenna because the GNSS repeater acts like a cable connecting outdoor antenna and indoor receiver. Therefore, the extra path delay (through the repeater) is common to all satellites in view, and is thus indistinguishable from the receiver clock offset. In this case, then, how can we determine user position using GNSS repeaters?

The basic idea underlying the use of repeaters is to simplify the need for additional infrastructure by using real GNSS signals. In particular, outdoor GNSS signals are amplified, switched, and/or delayed in order to be able to compute a position indoors. Pseudolites, in contrast, have their own pseudo-noise (PN) codes similar to those transmitted by the GNSS satellites.

GNSS signal switching

The key to using a GNSS repeater for positioning is a radio frequency (RF) switching device. This device takes a single input (i.e., the live signals from outdoors) and switches it among multiple re-radiation antennas, one at a time. By means of this time domain multiplexing, receivers can sequentially track GNSS signals from the multiple re-radiation antennas installed at different locations without self-interference.

With this switching among the re-radiation antennas a change occurs in the signal retransmission path. The change corresponds to the time difference of arrival (TDOA) between the switched retransmission antennas and the user. Therefore, if we have four retransmission antennas connected to the switching repeater, we can obtain three TDOA measurements for three-dimensional positioning, as shown in **Figure 1**.

TDOA measurements

The pseudorange measurement $Pr_i^k(t)$ between the k-th satellite and the receiver through the i-th re-radiation path at time t can be written as

$$Pr_i^k(t) = \rho_{sk}(t) + l_{c0} + l_{ci} + l_{ri}(t) + cb(t) \quad (1)$$

$\rho_{sk}(t)$: Geometric range between k-th satellite and reference antenna
l_{c0} : Cable length between reference antenna and switching repeater (known value)
l_{ci}: Cable length between switching repeater and i-th re-radiation antenna (known value)
$l_{ri}(t)$: Range between i-th re-radiation antenna and the receiver
$cb(t)$: Receiver clock bias

Suppose an antenna switching occurs at time t from antenna i to antenna j and the pseudorange between the k-th satellite and the receiver through the j-th re-radiation path is measured at time t+dt. The difference between range measurements at time t and t+dt can be written as

$$\Delta \mathrm{Pr}^{k}_{j,i}(t) = \mathrm{Pr}^{k}_{j}(t+dt) - \mathrm{Pr}^{k}_{i}(t) \quad (2)$$
$$= \left(\rho_{sk}(t+dt)l_{c0} + l_{cj} + l_{rj} + (t+dt) + cb(t+dt)\right) - \left(\rho_{sk}(t) + l_{c0} + l_{ci} + l_{ri}(t) + cb(t)\right)$$
$$= \left(\rho_{sk}(t+dt) - \rho_{sk}(t)\right) + \left(l_{cj} - l_{ci}\right) + \left(l_{rj}(t+dt) - (l_{ri}(t)\right) + \left(cb(t+dt) - cb(t)\right)$$

If the switching transition time dt is sufficiently small, we can assume that the user location does not change during this time interval for most indoor users and thus $l_{rj}(t + dt) \approx l_{rj}(t)$. The cable lengths are known fixed values and the cable length difference $l_{cj} - l_{ci}$ can be compensated.

The difference between satellite ranges $\rho_{sk}(t + dt) - \rho_{sk}(t)$ can be predicted mathematically or assumed to be same as the value $\rho_{sk}(t) - \rho_{sk}(t - dt)$ measured before antenna switching and also $(cb(t + dt) - cb(t))$ is assumed to be same as $(cb(t) - cb(t - dt))$. Therefore, the difference between two range measurements just before switching at time t and $t - dt$ can be assumed to be given by:

$$\Delta \mathrm{Pr}^{k}_{i,i}(t-dt) \approx \rho_{sk}(t+dt) - \rho_{sk}(t) + \left(cb(t+dt) - cb(t)\right)$$

From equation (2) and our foregoing assumptions, the TDOA measurement can be obtained by

$$\mathrm{TDOA}^{k}_{j,i}(t) = \mathrm{TDOA}_{j,i}(t) \triangleq l_{rj}(t) - l_{ri}(t) \quad (3)$$
$$\approx l_{rj}(t+dt) - l_{ri}(t)$$
$$= \Delta \mathrm{Pr}^{k}_{j,i}(t) - \left(\rho_{sk}(t+dt) - \rho_{sk}(t)\right) - (l_{cj} - l_{ci}) - (cb(t+dt) - cb(t))$$
$$\approx \Delta \mathrm{Pr}^{k}_{j,i}(t) - \Delta \mathrm{Pr}^{k}_{i,i}(t-dt) - (l_{cj} - l_{ci})$$

Note that for all visible satellites, the TDOA measurement will be the same because every satellite has same incremental pseudorange, that is

$$\mathrm{TDOA}_{j,i}(t) = \mathrm{TDOA}^{k}_{j,i}(t) = l_{rj}(t) - l_{ri}(t), \quad k = 1, 2, \ldots, N$$

where N is the number of satellites in view outdoors. The number of satellites in view outside is not important for the TDOA measurement itself; however, having more satellites can minimize the effect of measurement noise using averaging.

Figure 2 shows the differential pseudorange, $\Delta Pr^k(t) = Pr^k(t+1) - Pr^k(t)$ profile for the case of three antennas. The pseudorange measurements are logged at every 0.1 second and the antennas are switched every 0.5 second (denoted by the red dots). The jumps in differential pseudorange correspond to the TDOA between re-radiating antennas R1 and R2 and so on. We need at least three TDOA measurements to form hyperbolic positioning equations for 3D user position determination.

The problem of indoor repeater-based positioning thus consists of measuring the TDOA and the main technical issues are to detect and measure these code phase jumps at the time of signal switching. The problem of detecting and measuring a jump is often solved by maximum likelihood estimation. Alternatively, if the switching devices are synchronized to GNSS time and the switching sequence is pre-defined, one can detect the jumps much more easily.

Although switching the GNSS signal enables TDOA measurements, it also creates high dynamic stress in the receiver code-tracking loop. In order to cope with this effect, we need to widen

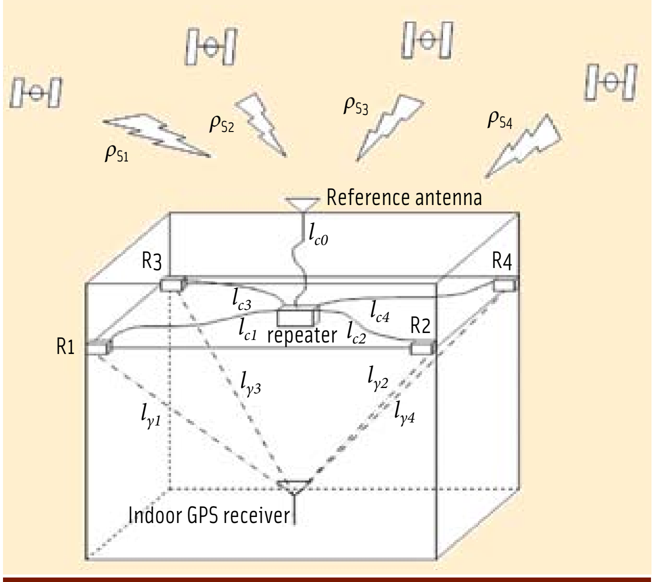

FIGURE 1 **Indoor positioning configuration with switching repeater with multiple re-radiation antennas**

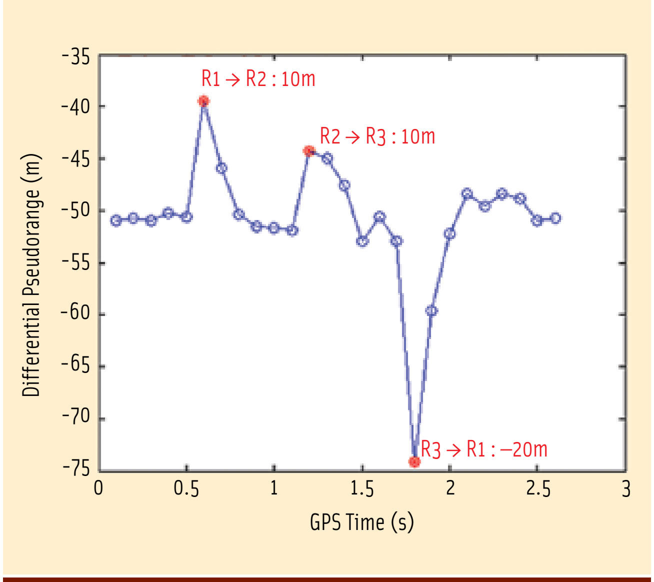

FIGURE 2 **Differential pseudorange for the case of three switching antennas**

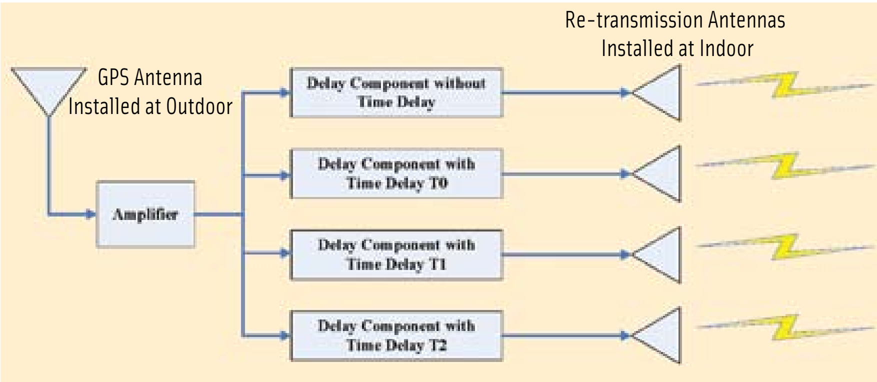

FIGURE 3 Time-delayed GNSS repeater configuration

the delay lock loop (DLL) bandwidth, which results in noisier code phase measurements. To mitigate this latter problem, we could use an RF signal-delaying operation instead of RF switching.

GNSS Signal Delaying

The basic idea of time-delayed repeater-based positioning involves use of the orthogonal property of direct sequence spread spectrum (DSSS) signals. For example, if two different re-radiation antennas with relative RF delays (intentionally induced) of more than two chips are placed in different spatial positions and continuously retransmit the common signal, the two different signals will not interfere with each other because of the orthogonal property of DSSS signals.

RF delay components such as optical fibers, programmable delay lines, and SAW (surface acoustic wave) filters can be used to generate the intentionally time-delayed signal.

Figure 3 shows a block diagram of the time-delayed GNSS repeater configuration. As drawn, the "delay components" are hardware components that each induce a known "time delay" (which could be zero) to the incoming signal.

Signals with different delays can be tracked without changing the receiver tracking loop bandwidth, and each pseudorange can be measured in a different GNSS receiver tracking channel.

Each measured pseudorange corresponds to the sum of the offset distance induced by delay line and the geometric distance between the receiver and the re-radiation antenna. Therefore, the difference of two measured pseudoranges is the TDOA measurement. Using this idea, if four retransmission antennas with different delays are used, the three-dimensional position of the receiver can be calculated.

Summary

If the use of GNSS repeater is allowed for certain indoor environments under RF radiation regulations, switching and/or delaying GNSS signals enables indoor positioning, without any new PN code and signal generator as with pseudolites. The positioning accuracy that can be achieved by this repeater-based positioning is reported at about 1–10 meters depending on the system configuration and indoor multipath environment.

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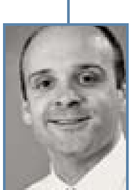

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